

# The influence of environmental factors on water mite assemblages (Acari, Hydrachnidia) in a small lowland river: an analysis at different levels of organization of the environment

Andrzej Zawal<sup>1</sup> · Robert Stryjecki<sup>2</sup> · Edyta Stępień<sup>3</sup> · Edyta Buczyńska<sup>2</sup> ·  
Paweł Buczyński<sup>4</sup> · Stanisław Czachorowski<sup>5</sup> · Joanna Pakulnicka<sup>5</sup> ·  
Przemysław Śmietana<sup>6</sup>

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**Abstract** Research on the ecology of water mites in flowing water has focused mainly on analysis of factors directly affecting these organisms in the aquatic environment. The hypothesis of this study was that apart from factors acting within the aquatic environment, the formation of Hydrachnidia communities in lotic ecosystems may also be affected by factors acting in the terrestrial environment. The analysis was made at three different levels of organization of the environment: (1) landscape level (sub-catchments, terrestrial environment), (2) macrohabitat level (sampling sites, aquatic environment) and (3) mesohabitat level (sampling sub-sites, aquatic environment). Some correlation was noted between certain species and some

sub-catchment parameters. This may indicate a link between some landscape features (terrestrial environment) and the formation of water mite assemblages in the river. The low percentage for physicochemical parameters together in explaining the variance in occurrence of species, very low correlations between species and physicochemical parameters and the discrepancy in the grouping of sites in the case of faunal data and data on the physicochemical indicates that physicochemical factors had little influence on water mites. Taking into account all three levels of organization of the environment analyzed, we can say that at the landscape level we can find only indirect relationships between environmental factors and the fauna inhabiting the aquatic environment; at the macrohabitat level the description of Hydrachnidia is more precise but still of a general nature. Only analysis at the mesohabitat level fully explains the specific character of Hydrachnidia assemblages.

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✉ Robert Stryjecki  
robstry@wp.pl

<sup>1</sup> Department of Invertebrate Zoology and Limnology, University of Szczecin, Wąska 13, 71-415 Szczecin, Poland

<sup>2</sup> Department of Zoology, Animal Ecology and Wildlife Management, University of Life Sciences in Lublin, Akademicka 13, 20-950 Lublin, Poland

<sup>3</sup> Department of Plant Taxonomy and Phytogeography, University of Szczecin, Wąska 13, 71-415 Szczecin, Poland

<sup>4</sup> Department of Zoology, Maria Curie-Skłodowska University, Akademicka 19, 20-033 Lublin, Poland

<sup>5</sup> Department of Ecology and Environment Protection, University of Warmia and Mazury, Pl. Łódzki 3, 70-727 Olsztyn, Poland

<sup>6</sup> Department of Ecology and Environmental Protection, University of Szczecin, Wąska 13, 71-415 Szczecin, Poland

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## Introduction

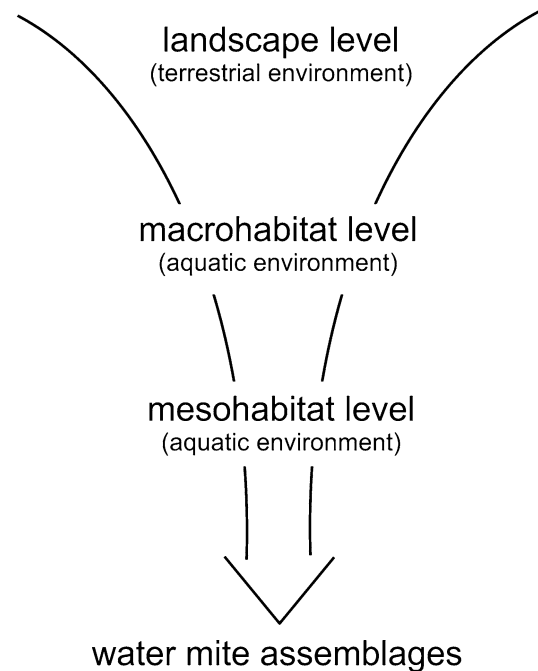
The Hydrachnidia (water mites) are one of the most ubiquitous components of the lotic communities in terms of both abundance and species richness (Di Sabatino et al. 2000, 2008). Research on the ecology of these mites in flowing water has focused mainly on analysis of factors directly affecting these organisms in the aquatic environment (Cicolani and Di Sabatino 1991; Gerecke and Schwoerbel 1991; Böttger and Martin 1995; Martin 1996; van der Hammen and Smit 1996; Martin 1997; Smit and van der Hammen 2000; Bagge 2001; Dohet et al. 2008; Boyací

et al. 2012; Goldschmidt 2016). This is understandable, as at the deutonymph and adult stages water mites are absolute hydrobionts. It should be remembered, however, that the developmental cycle of most species includes a parasitic phase outside the aquatic environment, as phoretic larvae of water mites living on the larvae and pupae of aquatic insects transfer to their adult forms and parasitize them outside the aquatic environment (Böttger 1976; Di Sabatino et al. 2000; Smith et al. 2001).

The terrestrial environment is usually ignored in studies of aquatic organisms, despite the fact that it can be an essential component of population dynamics and community structure in some aquatic taxa (Delettre et al. 1992; Delettre and Morvan 2000; Galic et al. 2013). Most work considering the effects of landscape structure on biodiversity and spatial distribution of various organisms has been devoted mainly to terrestrial organisms (see Delettre 2005). But not only terrestrial animals are affected by landscape dynamics: landscape structure and land use influence aquatic habitats and, consequently, aquatic invertebrate and vertebrate communities (Richards and Host 1994; Richards et al. 1996; Weigel et al. 2003; Diana et al. 2006; Miserendino and Masi 2010; Miserendino et al. 2011; Epele et al. 2012). For example, the possible influence of terrestrial landscape structure on the spatial distribution of adult Chironomidae emerging from water bodies was investigated by Delettre and Morvan (2000). One of the conclusions of this research was that the terrestrial environment is an essential component of population dynamics and community structure in aquatic Chironomidae. As part of the life cycle of water mites takes place outside the aquatic environment, it can be assumed that the formation of particular Hydrachnidia assemblages in a given lotic ecosystem may also be influenced by factors outside the aquatic environment affecting the hosts of water mite larvae, i.e., flying insects (e.g., Chironomidae).

The hypothesis of this study was that apart from factors acting within the aquatic environment (macro- and mesohabitat levels), the formation of Hydrachnidia communities in lotic ecosystems may also be affected by factors acting in the terrestrial environment (landscape level) (see Fig. 1).

It was assumed that environmental factors acting at the level of the landscape influence water mites indirectly by affecting their food base, predators and hosts of water mite larvae (aquatic insects), but also by determining the hydrological characteristics of the river. At this level it is most difficult to find relationships between the variables analyzed and Hydrachnidia assemblages because of the vast complexity of the system analyzed. At the macrohabitat level, variables affect the fauna more directly and thus relationships between habitat characteristics and a particular composition of fauna can be more precisely determined. At the mesohabitat level the variables act in an



**Fig. 1** Environmental factors affecting the formation of water mite assemblages in the river at three different levels of organization of the environment

even more precise manner, affecting the presence or absence of particular species (Fig. 1).

The aim of the study was to determine the effect of selected environmental and habitat factors acting at different levels of organization of the environment on the formation of Hydrachnidia assemblages in a small lowland river. The analysis included the effect of factors acting at the level of the landscape (sub-catchments), the level of the macrohabitat (sampling sites) and the level of mesohabitat (sampling sub-sites).

## Materials and methods

### Study area, sites and field work

The Krapiel is a small (length about 70 km) lowland coastal river situated in northwestern Poland. The Krapiel has its source in Chociwiec Lake (53°27'46.214"N, 15°20'52.503"E) and empties into the Ina River (53°19'08"N, 15°03'07"E). It has a diversified character: next to stretches with a rapid current and a bottom of stones and gravel, there are stretches with a slower water flow and a sandy or muddy bottom, as well as large marginal pools. The river flows through a variety of landscape structures: forests (hornbeam and oak, riparian forests and alder carrs), reeds and sedges, meadows, pastures, and urbanized areas. The valley contains floodplains and many oxbow lakes.

Also present are numerous springs, predominantly helocrenes. The water bodies of the river valley occur in various landscape structures: dense forest complexes, small, isolated forested areas and open land. For most of its course the water quality of the Krąpiel is of class I or II (Zawal 2014, unpublished).

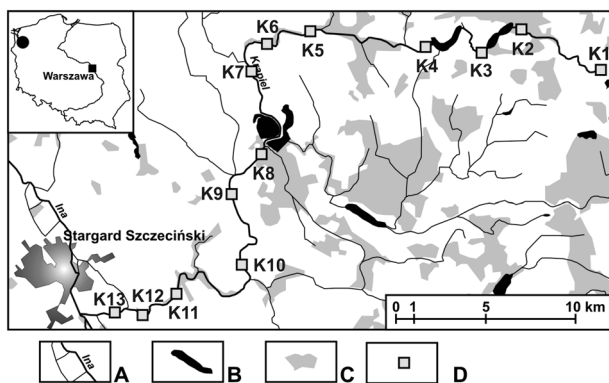
The research covered the entire length of the river: 13 study sites (K1–K13) were established along the river (Fig. 2). For study sites we use alternatively a term ‘macrohabitat’ in the meaning ‘a habitat of sufficient extent to present considerable variation of environment, contain varied ecological niches, and support a large and usually complex flora and fauna’ (Merriam-Webster Dictionary 2014). At each of the 13 sites (macrohabitats) samples were collected from several sub-sites (K1/1, K1/2, K1/3 etc.). For sub-sites we use alternatively a term ‘mesohabitat.’ The term mesohabitat refers to visually varied habitats that can be recognized subjectively by their physical similarity (e.g., a sandbank, a gravel bank or a particular plant community). This term introduces a dimension of scale and should be distinguished from microhabitats (e.g., a leaf stem or the surface of a stone) and macrohabitats (e.g., entire fragments of water bodies) (Armitage and Prado 1995). The number of mesohabitats taken into account resulted from the spatial differentiation of the particular site and was as follows: two mesohabitats at sites K4, K9 and K12, three at sites K2, K8 and K11, four at K3, K5, K7, K10 and K13 and five mesohabitats at K1 and K6. Altogether there were 45 sub-sites distributed in such a way as to cover all habitat types in which water mites occurred. A detailed list of sites (macrohabitats) and sub-sites (mesohabitats) is given in Online Resource 1 in the Electronic supplementary material (ESM). Fieldwork was conducted from April to October 2010. Samples were collected once a month, in the middle of each month. On each sampling date and in each mesohabitat three sub-

samples were collected for representativeness. Each sampling consisting of ten sweeps was taken using a kick-net sampler with 300- $\mu$ m mesh size and covered an area of about 0.5 m<sup>2</sup>, so the samples can be regarded as semi-quantitative. In some months samples from some sites and/or sub-sites were not collected because of hydrological conditions (very high or very low water level). A total of 810 samples were collected.

The catchment basin of the Krąpiel River was divided into 13 sub-catchments in such a way that each two adjacent sites (K1–K2, K2–K3, etc.) formed the boundaries of one sub-catchment. Each of 13 sub-catchments corresponded to a particular study site (sub-catchment 1 for study site K1, sub-catchment 2 for study site K2, etc.). The following basic parameters at the landscape level were measured and described for each sub-catchment: combined surface area of the sub-catchment of all sampling sites from the source to the site, surface area of the sub-catchment of each site, the length of the boundaries of the sub-catchment, roughness (Ra) (Jenness 2004), Contagion Index (C) (McGarigal and Marks 1995), river gradient and distance from the source as well as the surface area of patches of different types present in the sub-catchment (forests, fields, swamps, built-up areas, meadows, shrubs, barren areas and water bodies) and their average distance from the river. In total 23 parameters at the landscape level were analyzed, and their values are given in Table 1.

Temperature, pH, electrolytic conductivity and dissolved oxygen content were measured with an CX-401 multifunction meter (Elmetron, Zabrze, Poland), water flow using a SonTek acoustic FlowTracker flowmeter (SonTek, San Diego, USA), BOD<sub>5</sub> by Winkler’s method, insolation with a CEM DT-1309 light meter (Merazet, Poznań, Poland) and the remaining parameters (NO<sub>3</sub>, NH<sub>4</sub>, PO<sub>4</sub>, Fe, turbidity and hardness) with a Slandi LF205 photometer (Slandi, Michałowice, Poland). Three measurements were performed each time, and the median was used for further analysis. In total 11 parameters at the macrohabitat level were analyzed, and their values are given in Table 1.

Parameters characterizing individual mesohabitats (velocity, insolation, degree of aquatic plant cover—plants, and substrate type and structure: organic, mineral, mean sediment grain size—M, and sediment sorting—W) were measured and described. Vegetation cover was determined on a scale of 0–5 as follows: 0—complete lack of vegetation at sampling site, 1—1–10% bottom cover by plants, 2—11–30% bottom cover, 3—1–50%, 4—51–75% and 5—76–100%. The degree of bottom cover by vegetation was estimated visually. In total seven parameters at the mesohabitat level were analyzed, and their values are given in Table 1.



**Fig. 2** Location of the sampling sites: A rivers, B lakes and fish ponds, C forests and D sampling sites (one sampling site in each sub-catchment K1–K13). The direction of flow is from K1 to K13

**Table 1** Values for analyzed parameters

	Min	Max
Parameters measured at the landscape level (parameters of the sub-catchments)		
Combined surface area of the sub-catchment from the source to individual sites (as % of total catchment area of the river)	0.77	100.0
Surface area of the sub-catchment of each site (as % of total catchment area of the river)	0.77	30.4
Length of catchment boundaries (in kilometers)	12.4	107.6
Roughness (Ra)	9.2	24.4
Contagion index ( <i>C</i> )	1.5	2.7
River gradient (‰)	0.1	4.8
Distance from the source of individual sub-catchments (in km)	2.1	64.3
Forests (as % of the area of the sub-catchment)	6.6	41.4
Fields (as % of the area of the sub-catchment)	23.7	80.9
Swamps (as % of the area of the sub-catchment)	0.0	3.4
Built-up areas (as % of the area of the sub-catchment)	0.9	8.2
Meadows (as % of the area of the sub-catchment)	4.4	36.9
Shrubs (as % of the area of the sub-catchment)	0.0	0.7
Barren areas (as % of the area of the sub-catchment)	0.0	1.8
Water bodies (as % of the area of the sub-catchment)	0.04	4.8
Forests—distance from the river (in km)	0.0	2.6
Fields—distance from the river (in km)	0.0	3.1
Swamps—distance from the river (in km)	0.0	1.5
Built-up areas—distance from the river (in km)	0.0	2.2
Meadows—distance from the river (in km)	0.0	2.7
Shrubs—distance from the river (in km)	0.0	1.5
Barren areas—distance from the river (in km)	0.0	1.6
Water bodies—distance from the river (in km)	0.0	2.6
Parameters measured at the macrohabitat level (hydrochemical parameters of water)		
Water temperature (°C)	6.4	25.1
pH	5.55	9.80
Conductivity ( $\mu\text{S cm}^{-1}$ )	65	305
Dissolved oxygen $\text{O}_2$ ( $\text{mg l}^{-1}$ )	1.1	14.9
$\text{BOD}_5$ ( $\text{mg l}^{-1}$ )	0.0	8.5
$\text{NH}_4$ ( $\text{mg l}^{-1}$ )	0.1	3.0
$\text{NO}_3$ ( $\text{mg l}^{-1}$ )	0.2	8.8
$\text{PO}_4$ ( $\text{mg l}^{-1}$ )	0.1	1.0
Fe ( $\text{mg l}^{-1}$ )	0.0	1.7
Solid concentration ( $\text{mg l}^{-1}$ )	0.0	304
Hardness ( $\text{mg l}^{-1}$ )	25	288
Parameters measured at the mesohabitat level (sediments and other parameters)		
Organic sediments (%)	0.0	55.5
Mineral sediments (%)	0.0	100.0
Mean sediment grain size— <i>M</i> (in millimeters)	0.02	2.79
Sediment sorting— <i>W</i>	0.53	2.3
Aquatic plant cover (on a scale from 0 to 5)	0	5
Insolation (%)	0.0	100.0
Water flow ( $\text{m/s}$ )	0.0	1.17

## Laboratory work

Bottom sediment analysis included determination of grain size and content of organic and mineral matter. Samples were collected by hand using a container with a capacity of 1 l. The Krumbein scale was used in the granulometric analysis, with grain size ( $d$ ) in mm expressed in phi units ( $\varphi$ ), where:

$$\varphi = -\log_2 d \text{ (mm)}$$

The following calculations were made: mean grain size (graphic arithmetic mean), i.e., mean diameter  $M = (\varphi_{16} + \varphi_{50} + \varphi_{84})/3$ , and sediment sorting (graphic standard deviation), which is a measure of the dispersion of grain diameter values:  $W = [(\varphi_{84} - \varphi_{16})/4] + [(\varphi_{95} - \varphi_5)/6.6]$ .

Individual sediment samples were freeze-dried using a Christ Alpha 1-2 LD Freeze Dryer (Martin Christ Gefriertrocknungsanlagen GmbH, Osterode am Harz, Germany), and then organic matter was removed from each sample by heating the sample in a Nabertherm High-Temp Muffle Furnace at 550 °C (Nabertherm GmbH) to obtain a solid mass. In this manner the percentages of mineral and organic matter were determined.

## Statistical analyses

Similarities between parameters were determined using BIODIVERSITY PRO v.2 software (McAleece et al. 1997). The Euclidian distance formula was used for abiotic parameters (parameters of the sub-catchment and physical and chemical properties of water) and the Bray-Curtis formula for faunal similarities (water mite fauna). The group-average clustering method was used.

The detrended correspondence analysis (DCA) between the composition of water mite taxa and different sub-catchment parameters showed that the length of gradient represented by the first ordination axis equaled 4.893, proving that the species realized the full Gaussian spectrum, which justified conducting the direct ordination analyses of the canonical correspondence analysis (CCA) type in order to identify relations between the occurrence of species and different sub-catchment parameters taken into account. The significance of the effect of respective environmental parameters on the diversity of species composition was determined using stepwise variable selection ( $p \leq 0.05$ ). Monte Carlo test with 499 permutations was conducted in order to pinpoint the most significant variables.

Significance of differences in the abundance of particular species in macrohabitats was tested by non-parametric analysis of variance (Kruskal-Wallis test), and a non-parametric Spearman rank correlation ( $r_s$ ) was used to

calculate correlations. Statistica 10.0 software was used for calculation.

## Results

A total of 9375 water mite individuals were caught with 116 species belonging to 28 genera and 19 families (Table 2, Online Resource 2 in the ESM).

### Landscape level

Figure 3a presents a dendrogram grouping the sub-catchments of individual sampling sites (K1–13). Three clusters can be seen. The first cluster consists of the sub-catchments of sites situated in the upper course of the river (K1–K5). The greatest similarity within this aggregation, between the sub-catchments of sites K3 and K4, was 99.3%. The next group consists of the sub-catchments of the sites located in the middle course of the river (K6–K10). The greatest similarity within this cluster was noted between the sub-catchments of sites K6 and K7 (98.6%). The third aggregation is composed of the sub-catchments of the sites in the lower course of the river (K11–K13). Within this cluster the greatest similarity was noted between the sub-catchments of sites K12 and K13 (99.6%). The main sub-catchment parameters grouping the sites were distant from the source, surface area of the sub-catchment and the river gradient in this sub-catchment area.

Figure 4 presents relationships between Hydrachnidia fauna and selected sub-catchment parameters (only statistically significant correlations are presented). Six variables together explain 29.3% of the total variance in the occurrence of species. In the upper right-hand corner of the diagram we can see a group of species closely associated with the parameter ‘shrub area.’ This group includes standing water species of the genera *Limnesia* [*L. fulgida* Koch, 1836, *L. maculata* (Müller, 1776) and *L. undulatoidea* Davids, 1997], *Piona* (*P. coccinea* (Koch, 1836)] and *Arrenurus* [*A. batillifer* Koenike, 1896, *A. bruzelii* Koenike, 1885, *A. cuspidator* (Müller, 1776), *A. globator* (Müller, 1776), *A. integrator* (Müller, 1776), *A. maculator* (Müller, 1776) and *A. tubulator* (Müller, 1776)]. Another group of species is associated with the parameter ‘river gradient’ (lower right-hand corner of the diagram). This group includes rheobiontic species (e.g., *Sperchonopsis verrucosa* (Protz, 1896) and *Atractides nodipalpis* Thor, 1899) and rheophilic species (*Hygrobatas setosus* Besseling, 1942), but also species preferring marginal pools (*Hygrobatas nigromaculatus* Lebert, 1879). The third group of species was associated with several sub-catchment parameters (‘catchment area,’ ‘river area,’ ‘distance to forest’ and ‘distance to source’), the most important of



**Table 2** Number of water mite specimens and species collected at each site in the Krapiel River

Study site	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	Total
Specimens	15	11	13	30	164	638	1425	470	523	2761	855	382	2088	9375
Species	6	5	2	14	18	28	53	44	31	36	34	27	31	116

K1–K13—study sites (macrohabitats)

which was ‘distance to source.’ The most abundant species in this group were *Torrenticola amplexa* (Koenike, 1908), *T. brevirostris* (Halbert, 1911) and *Sperchon clupeiifer* Piersig, 1896. These species occurred in very high numbers at site K10 (Online Resource 2 in the ESM).

### Macrohabitat level

Substantial differences were noted in the number of individuals and species caught at different sampling sites (macrohabitats) (Table 2). The differences in the number of individuals were statistically significant (Kruskal-Wallis test:  $H(12, N = 396) = 51.75947$   $p < 0.001$ ).

Figure 3b shows the faunal similarities between sampling sites. Faunistic similarity between sites ranged from 0.0 to 49.03% (Table 3). The highest similarity of fauna was noted between sites K11 and K13 (49.03%), followed by sites K6 and K7 (47.76%) and sites K11 and K12 (42.12%). A tendency can be seen for water mite assemblages from successive sites along the length of the river to be grouped together (e.g., a cluster including sites K1, K3 and K4; a pair K6–7, a cluster including sites K11–13). The fauna of site K2 clearly stands apart.

Figure 5 presents relationships between the distribution of water mite fauna and physicochemical parameters (only statistically significant correlations are presented). Six variables (pH, temperature, BOD<sub>5</sub>, O<sub>2</sub>, NH<sub>4</sub> and NO<sub>3</sub>) explain together a total of 20.7% of the total variance in the occurrence of species. On the right side of the diagram are species characteristic of standing water bodies, mainly of the genus *Arrenurus*. Their distribution in the river was not associated with any of the analyzed physicochemical parameters. On the left, the majority of species are associated with rheocoenoses and belong to the genera *Torrenticola*, *Sperchon*, *Atractides* and *Lebertia*. Of the six statistically significant parameters influencing the distribution of fauna, the influence of pH was greatest, but the correlations between particular species and pH were very low and in most cases statistically insignificant (Table 3). Apart from pH, the parameter having the greatest influence on the character of the fauna was temperature, but as in the case of pH, the correlations between water temperature and particular species were very low and in most cases statistically insignificant.

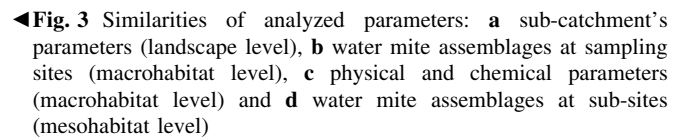
Figure 3c shows similarities between the physicochemical parameters of the water at different sampling sites

(macrohabitats). Three clusters are visible in the diagram. Cluster 1 groups sites from the lower course of the river (K8–K12), but also the first two sites (K1 and K2). Cluster 2 includes sites situated in the middle course of the river (K5–K7), but also one site from the lower reaches (K11). Cluster 3 contains two sites from the beginning of the course of the river (K3 and K4), but also the last site along its course (K13).

### Mesohabitat level

Figure 3d shows the faunal similarities between sub-sites (mesohabitats). For greater clarity, only similarities above 60.0% are shown in the diagram. Faunistic similarity values between sub-sites ranged from 0.0% to 73.93% (Table 3). The highest similarity of fauna was noted between sub-sites K12/1 and K13/2 (73.93%). The habitat characteristics linking these two sub-sites were substrate type (sandy) and slow water flow (see Online Resource 1 in the ESM). The second highest faunistic similarity was noted between sub-sites K10/3 and K11/2 (73.45%). In both sub-sites the substrate was sandy, but the water flow in them was different—slow at sub-site K10/3 and fast at sub-site K11/2 (Online Resource 1 in the ESM). High faunistic similarity was also observed between sub-sites within the same site (no. K7/2–K7/3, K6/1–K6/4 and K10/2–K10/4), but these values were lower than for similarity between sub-sites from different sites (Fig. 3d).

Figure 6 presents relationships between water mite distribution and environmental parameters measured at mesohabitat level. Seven variables used in the ordination explain 19.1% of the total water mite species variance. Three of them (velocity, plants and insolation) were statistically significant and explained 18.1% of the total variance in the occurrence of species (velocity—6.6%, plants—5.8% and insolation—5.7%). In the upper left-hand quarter of the diagram species whose distribution was most determined by current velocity are grouped together. The species associated with this environmental factor were *Torrenticola brevirostris*, *T. amplexa*, *Sperchon clupeiifer*, *Hygrobates calliger* Piersig, 1896, *Lebertia pusilla* Koenike, 1911, and *Atractides nodipalpis* (Fig. 6). The species most strongly associated with current velocity was *Torrenticola amplexa* ( $r_s = 0.49$ ,  $p = 0.001$ ). All these species were caught in the highest numbers in the mesohabitats at site K10, with well-developed lotic zones



**Fig. 4** CCA diagram displaying the relationship between the composition of water mite fauna and different sub-catchment parameters (see Online Resource 2 for full names of species)

(mesohabitats K10/1, 2 and K10/4) (Online Resources 1 and 2 in the ESM). At the opposite pole are species associated with a fine substrate (*M*). In the upper right-hand corner of the diagram we can see a group of species whose distribution in the river depended on a group of co-occurring factors—plants, organic substrate and insolation, of which the most important factor was plants (Fig. 6). A bottom covered with macrophytes was mainly associated with stagnobiontic species of the genera *Limnesia*, *Piona* and *Arrenurus*.

## Discussion

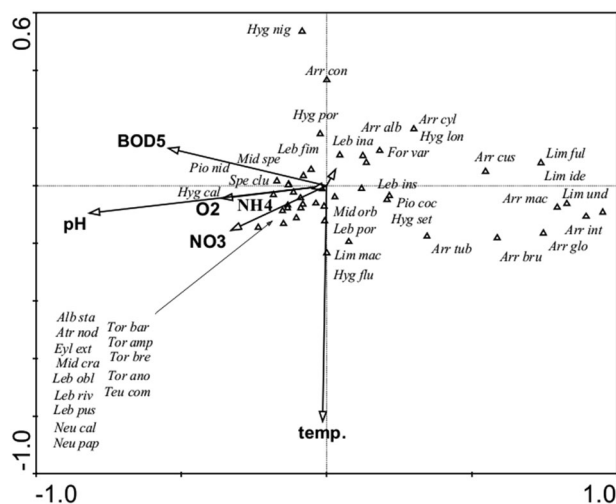
Several studies show that the structure of macroinvertebrate assemblages in aquatic ecosystems is determined not only by factors acting within the aquatic environment but also by factors acting on a larger spatial scale, outside of the aquatic environment. Weigel et al. (2003) found that assemblages of aquatic macroinvertebrates, at the catchment scale, were shaped by the percentage of forest cover, catchment size, groundwater delivery, percentage of wetland cover and geographical sampling location. Epele et al. (2012) found that land-use practices may have significant

**Table 3** Values for selected statistical data for macrohabitat and mesohabitat levels

Level of analyses	Range of values of faunistic similarities (in %)	Range of values of correlation coefficients	Percentage of correlations statistically significant
Macrohabitat level	0.0–49.03	–0.25 to +0.27	14.44
Mesohabitat level	0.0–73.93	–0.39 to +0.49	24.41

Macrohabitat level: faunistic similarities between sampling sites; correlations: between water mite fauna and physicochemical parameters (11 parameters listed in Table 1)

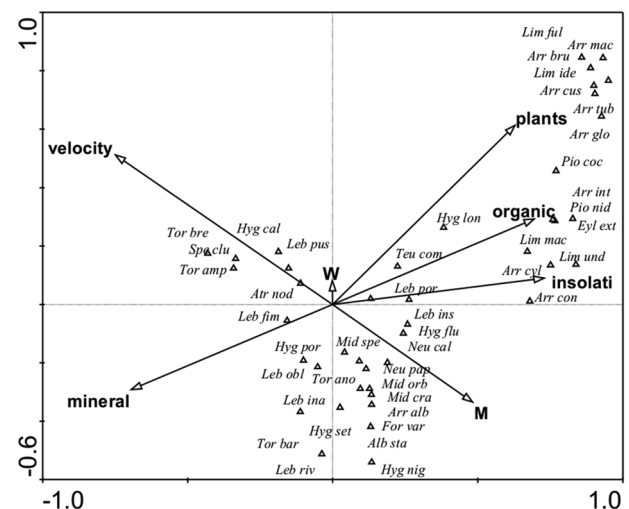
Mesohabitat level: faunistic similarities between sub-sites; correlation: between water mite fauna and environmental parameters measured at the mesohabitat level (7 parameters listed in Table 1)



**Fig. 5** The CCA diagram displaying the relationships between the composition of water mite fauna and different physical and chemical parameters of the water (only statistically significant correlations/parameters are shown). See Online Resource 2 for full names of species

effects on ecological stream attributes such as increased turbidity, sediment deposition and runoff patterns, which can alter assemblages of Chironomidae inhabiting an aquatic environment. The results of a study by Miserendino and Masi (2010) confirm that macroinvertebrate assemblage structure in Patagonian low-order streams can be altered by land-use practices. Miserendino et al. (2011) found a relationship between land-use intensity and water quality, stream habitat and biodiversity, which in consequence affects aquatic macroinvertebrate assemblages. Stryjecki et al. (2016) found that certain landscape parameters as well as spatial arrangement of the water bodies in the landscape had a strong influence on species composition and abundance of water mite fauna.

Comparison of the similarities between the sub-catchments of individual sites (Fig. 3a) and the similarities of fauna from individual sites (Fig. 3b) shows a similar pattern of cluster formation. The similar grouping of sub-



**Fig. 6** The CCA diagram displaying the relationships between the composition of water mite fauna and different biotic and abiotic environmental parameters. *Mineral* mineral sediments, *organic* organic sediments, *M* mean sediment grain size, *W* sediment sorting. See Online Resource 2 for full names of species

catchment and faunal parameters may indicate a cause-and-effect relationship between the landscape and macrohabitat levels. The strongest correlation was noted between certain species of the genera *Limnesia*, *Piona* and *Arrenurus* and the area covered with shrubs in the sub-catchments (Fig. 4). Of course this must be regarded as an indirect link. The group of species grouped around the vector ‘shrub area’ consists of water mites associated with standing water. These water mites have a parasitic phase in their life cycle; their larvae parasitize terrestrial insects, mainly Chironomidae (Kouwets and Davids 1984; Smith and Oliver 1986), but also Odonata (Biesiadka 2008; Zawal and Buczyński 2013). A likely explanation for this relationship at the landscape scale—between species of the genera *Limnesia*, *Piona* and *Arrenurus* and shrub area—may be the fact that the host insects find better conditions for development in terrain covered with shrubs than in open



terrain. Delletre and Morvan (2000) found that adults of aquatic chironomids accumulate in higher numbers in well-structured hedges, which provide the best shelter for insects at rest, while degraded hedges with very low grass cover harbor fewer species and individuals. Some Odonata species also show a predilection for areas covered with shrubs (Balzan 2012). Thus certain groups of insects that are hosts for water mite larvae may be influenced by landscape parameters (e.g., shrub area), and this fact may in turn affect the formation of Hydrachnidia assemblages in the river.

Temperature plays an essential role in shaping water mite assemblages and influences the altitudinal and latitudinal distribution patterns of species (Di Sabatino et al. 2000). Of course, other factors, such as pH, oxygen, electrolyte concentration, trophic conditions and other physicochemical parameters may also play a role in the formation of water mite assemblages (Schwoerbel 1959; Rundle and Hildrew 1990; Smit and van der Hammen 1992; van der Hammen and Smith 1996; Smit and van der Hammen 2000). The Krąpiel is a lowland river inhabited by eurythermic species, so it is difficult to identify clear relationships between temperature and the occurrence of particular species. Also, no clear relationship between other physicochemical parameters and the occurrence of particular species was found. As the values for the physicochemical parameters were not extreme (Table 1) and in general within the tolerance ranges for the species recorded (van der Hammen and Smit 1996; Smit and van der Hammen 2000), the lack of a clear relationship between physicochemical properties of water and the faunal composition is unsurprising. Taking into account all factors, the low percentage of physicochemical parameters together in explaining the variance in occurrence of species, the very low values for individual parameters, the very low correlations between species and physicochemical parameters, and the discrepancy in the grouping of sites according to faunal data (Fig. 3b) and the physicochemical parameters (Fig. 3c), we can conclude that factors other than the physical and chemical parameters influence the distribution of fauna in the river.

Of the parameters analyzed at the mesohabitat scale, velocity, plants and insolation had the greatest effect on the occurrence of species. Water current is one of the basic factors influencing the formation of water mite assemblages in lotic ecosystems (Böttger and Martin 1995; van der Hammen and Smit 1996; Martin 1996, 1997). In the fauna of the Krąpiel the species most closely associated with this factor were *Torrenticola brevisrostris*, *T. amplexa*, *Sperchon clupeiifer*, *Hygrobates calliger*, *Lebertia pusilla* and *Atractides nodipalpis* (Fig. 6). As all these species are rheobionts (Böttger and Martin 1995; van der Hammen and Smit 1996; Di Sabatino et al. 2010), it is unsurprising that

rapid water flow is a deciding factor influencing their distribution. All these species were caught in the highest numbers in the mesohabitats at site K10 (K10/1–2), with well-developed lotic zones, but they were also numerous at mesohabitats K11/1–2, K13/1 and K13/4 (Online Resources 1 and 2 in the ESM). Other important factors influencing the distribution of water mites in the Krąpiel at the mesohabitat level were insolation and the degree of vegetation cover of the bottom. These factors are obviously correlated: water mites, as heterotrophic organisms, are not dependent on the availability of light, but a bottom covered with macrophytes was mainly associated with the presence of lenitobionts of the genera *Limnesia*, *Piona* and *Arrenurus* (Fig. 6), species characteristic of small, eutrophic and densely overgrown water bodies or the phytolittoral zone of lakes (Biesiadka and Kowalik 1991). In such habitats with slow water flow over organic sediment, the occurrence of species characteristic of standing water bodies is possible. These species were caught mainly in marginal pools and in mesohabitats with well-developed aquatic vegetation, such as K7/2–3 or K8/1–3 (Online Resources 1 and 2 in the ESM). The significant proportion of rheoxenes in lowland river fauna in certain habitats is a natural phenomenon (Böttger and Hoerschelmann 1991; Cichocka 2006; Stryjecki 2009).

In comparison with the macrohabitat level, mesohabitats are characteristic in higher values for faunistic similarity and higher correlations between water mites and several parameters (Table 3). This indicates that factors at the mesohabitat level explain specific water mite assemblages much more precisely than factors acting at the macrohabitat level. For example, when we analyze relationships between water mites and physicochemical parameters (analyses at the macrohabitat level), it is difficult to explain precisely why particular species are arranged on the CCA diagram in this manner (Fig. 5). However, when we take into consideration analyses at the mesohabitat level, it becomes clearer that there are factors other than the physicochemical parameters (mainly water current and plants—factors acting at the mesohabitat level, Fig. 6) that have led to the observed distribution of species. This conclusion, that mesohabitat features are crucial in explaining the synecological structure of the fauna, is supported by other authors, whose studies have shown that the structure of the environment at the mesohabitat level explains the presence of particular taxa because it is an ecological niche for these species (Johnson and Jennings 1998; Weigel et al. 2003; Bonada et al. 2006; Epele et al. 2012; García-Roger et al. 2013). Taking into account all three levels of organization of the environment analyzed in this study, we can conclude that at the landscape level we can find only indirect relationships between environmental factors and the fauna inhabiting the aquatic environment.

At the macrohabitat level the description of Hydrachnidia is more precise but still of a general nature, and it is only the mesohabitat level that fully explains the structure of Hydrachnidia assemblages (Fig. 1).

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